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THE MARINE TERTIARY OF THE WEST COAST OF THE UNITED STATES: ITS SEQUENCE, PALEOGEOGRAPHY, AND THE PROBLEMS OF CORRELATION[1]

BRUCE L. CLARK
University of California, Berkeley

INTRODUCTION

Considerable work has been done on the marine Tertiary deposits of the West Coast during the past ten years, and some of the discoveries that have been made have greatly modified many of our previous conceptions. The purpose of this paper is to review some of the most salient facts concerning the stratigraphic divisions, paleogeography, and correlation of these horizons in order to give the reader some idea of the present status of this knowledge.

The paper includes a correlation table of the marine West Coast Tertiary. The construction of such a table is a very difficult task, and it will undoubtedly be a good many years before a table can be made which will be satisfactory to everyone working in this field. None of the West Coast Tertiary horizons has been thoroughly studied: there is a notable lack of detailed mapping, and most of the faunas have been inadequately monographed. The West Coast Tertiary still offers some of the most important problems for stratigraphic and paleontological research in the United States, and if the reader can obtain from this paper some

[1] Read before Geological Society of America, December, 1920.

idea of the problems involved, the task will have been well worth while.

There are several factors, aside from the lack of a sufficient number of trained workers, that have hindered the progress of correlation of West Coast horizons. These factors may be considered under the following headings: (1) temperature differentiation (2) geographical isolation, and (3) poor preservation.

1. It is well known that the marine faunas living on the Pacific Coast can be separated into distinct faunal and geographical provinces. In this respect the West Coast of North America is typical of the whole Pacific border. For example, the fauna found off the coast of Panama is very different from that living along the coast of southern California, and the latter has very little in common with that off the coast of Alaska, while faunas from some of the intermediate areas are almost equally distinct.[1] It is generally recognized that Pleistocene and Recent times mark one of the maximum periods of emergence of all the continents. While this is not true in so great a measure of all the periods of the Tertiary, it is well known that the North American continent was submerged only on its borders, and that during a large part of this time the Pacific and Atlantic oceans were disconnected. The study of the Tertiary faunas along the coast discloses marked evidences of temperature differentiation; the faunas of the north having a more boreal aspect than those of the south.[2] This differentiation was most exterme in the Pliocene and Upper Miocene, and it is undoubtedly because of this that there has been so much confusion in the past in the correlation of the deposits from various sections along the coast now referred to those horizons. There is good evidence of temperature differentiation during the Oligocene and Middle Miocene, and what is more interesting is that accumulated evidence seems to show that this differentiation of the faunas had its effects even as far back as Eocene times.

[1] W. D. Dall, *Summary of the Marne Shellbearing Mollusks of the Northwest Coast of America, Bulletin 112, United States Natural Museum* (1921), pp. 1–213.

[2] J. P. Smith, "Climatic Relations of the Tertiary and Quaternary Faunas of the California Region," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. IX (1919), No. 4, pp. 123–73.

2. The second factor, that of geographical isolation, was very probably an important one, and if so was the result of numerous partially isolated local basins of deposition. The sediments of the Tertiary were for the most part laid down in geosynclinal troughs which paralleled the present Coast ranges. The number and position of these troughs has varied through the different periods and epochs of deposition. There was therefore a condition similar to that which existed in the Appalachian geosyncline during the Paleozoic. Great thicknesses of clastic sediments, in aggregate exceeding 40,000 feet, were deposited on the West Coast during Tertiary time. These Tertiary basins existed either as large embayments or long inland seas, some of the latter of which were comparable in size to the Mediterranean and were probably nearly as well separated from the main ocean basin. These conditions produced marked local environments, with corresponding local changes in the faunas. It is very probable that the faunas in each basin derived certain peculiar characteristics due to isolation alone.

3. Still another factor that has brought about difficulties in correlation in the West Coast Tertiary has been the rather general poor preservation of the fossil material. The Tertiary beds have been extensively folded and tilted, and this deformation has resulted in the leaching of the original material of the shells, especially in the sandstones and shales. Intensive collecting will in time remedy this difficulty as well as bring to our knowledge a larger number of localities where the fossils are in a better state of preservation.

In presenting a correlation table of this kind, one of the first things that will be asked is the author's point of view in attacking the problems. The point of view accepted is that diastrophism is the fundamental basis for differentiating geologic divisions. In other words, the divisions recognized in this paper have been made on the basis of stratigraphic breaks which are believed to be more than local. It is important to note that every stratigraphic unit thus recognized is also represented by a distinctive fauna.

The paleogeographic maps presented in this paper are not accurate in detail and will undoubtedly be modified by future work. The present knowledge of the geology of the Coast ranges

does not enable one to show the exact location of the shore lines of all the seas that have occupied this general area. However, it is believed that the plates show the approximate distribution of the seas and will give the reader some conception of the location of the most important land masses, the degree of isolation of the basins, and the present known extent of the Tertiary horizons in California.

TERTIARY DIVISIONS

There are at least five major divisions of the Tertiary of the West Coast which in the writer's estimation might be recognized as representing true periods. Each one of these five major divisions is composed of more than one epoch of deposition. Each epoch is represented by distinct faunas which lived in distinct seas. The deposits belonging to each of the major divisions will be referred to as a "series"; thus, the Eocene, Oligocene, Lower-Middle Miocene, Upper Miocene, and Pliocene series. To the deposits of each epoch of deposition the term "group" has been applied. The term "formation" is reserved for the lithologic member within the group.

EOCENE

During the Eocene period of the West Coast there were at least three epochs of deposition, as indicated in the correlation table, and there is a suggestion that there were four and possibly five. At the present time, however, only three distinct stratigraphic divisions have been definitely separated. These are the Martinez (Lower Eocene), Meganos (Middle Eocene), and the Tejon (Upper Eocene). Crustal movements of considerable magnitude separated these epochs. In the region of Mount Diablo, middle California, there is a difference in dip and strike between the Martinez and Meganos groups. Over large areas along the coast where beds of the Meganos and Tejon deposits occur in contact, there is an angular unconformity separating the two. The marine faunas of these three divisions of the Eocene differ greatly from each other, further substantiating the stratigraphic evidence of marked

hiatuses.[1] Thus, on the West Coast, the Eocene period may be definitely stated to be made up of at least three epochs of deposition and should be recognized as a true period rather than as an epoch.

Correlation of Eocene deposits.—The evidence for the correlation of the West Coast marine Eocene with that of the Gulf and East Coast provinces and through them with Europe is based upon the identity of species or the presence of closely related forms common to the two regions. The evidence appears to be much better for the correlation of the Meganos and the Tejon (Middle and Upper Eocene) than for the Lower or Martinez group. There can be little doubt but that during those epochs of time there was a direct connection between the Gulf of Mexico and the Pacific Ocean.

Climate.—The climate during the Eocene of the West Coast was subtropical or possibly warm temperate rather than tropical. The arkosic character of the Meganos deposits, a character very general on the West Coast, strongly suggests that we are dealing with deposits which were derived from an arid coast, while Tejon sandstones, at most localities in California, are composed almost entirely of pure quartz grains, indicating humid climatic conditions at that time.[2]

(Fig. 1.) *Paleogeography.*—As indicated by the paleogeographic maps, the deposits of the Martinez group (Lower Eocene, Fig. 2) were laid down in much more limited basins than those of the Meganos and Tejon groups. Apparently there were at least four separate basins in California, the connections between which were indirect. It seems very probable that when the faunas obtained from these four areas have been more fully described, we shall find that the geographical factor has caused considerable difference between them.

[1] R. E. Dickerson, "Fauna of the Martinez Eocene of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1914), No. 6, pp. 61–180. B. L. Clark, "The Meganos Group, a Newly Recognized Division in the Eocene of California," *Bull. Geol. Soc. Am.*, Vol. XXVIII (1918), pp. 218–96; "Stratigraphy and Faunal Relationships of the Meganos Group, Middle Eocene of California," *Jour. Geol.*, Vol. XXIX (1921), No. 2, pp. 125–65.

[2] R. E. Dickerson, "Climatic Zones of Martinez Eocene Time," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 7, pp. 193–96.

The Meganos and the Tejon seas (Figs. 3 and 4) were somewhat similar in outline. In middle California the deposits of these epochs were laid down in a great trough of which the present Great Valley of California is a remnant. The Meganos sea was the wider of the two Eocene seas that occupied this depression

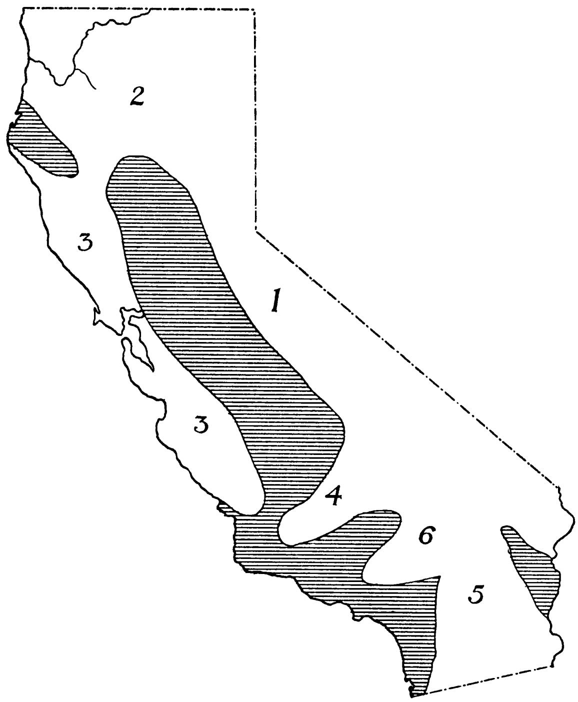

FIG. 1.—A key map showing the general distribution of positive and negative areas in California during the Tertiary. Of all the positive areas outlined, No. 6, the Santa Monica Mountain area, is the most problematical. (1) Sierra Nevada area; (2) Klamath Mountain area; (3) Coast Range area; (4) Tehachapi Peninsula; (5) Sierra Madre, San Bernardino, San Jacinto Mountain area; (6) Santa Monica Mountain area.

and was connected with an east and west trough in southern California in the region of the present Santa Ynez Mountains. These two general areas of deposition existed throughout the Tertiary. They were bordered by areas or zones of uplift which have also been more or less permanent. East of the great north and south trough was the Sierra Nevada block which dates back to the Upper

Jurassic. To the west there was a positive area covering the present western side of the Coast ranges of middle California. Apparently throughout the entire Eocene period this area to the west was a positive block; the absence of either continental or marine deposits in this area is the chief basis for the conclusion.

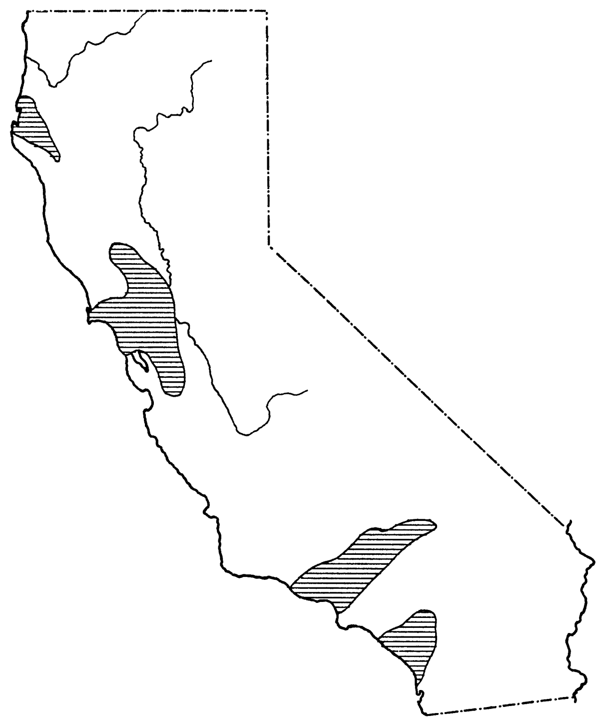

FIG. 2.—Martinez (Lower Eocene)

The smaller positive and negative areas which existed during the Oligocene, Miocene, and Pliocene in this western area were not differentiated during the Eocene.

One of the most permanent positive areas of the Tertiary was that which existed in the region now occupied by the Tehachapi and San Emigdio Mountains (Fig. 1). This area formed the east-west peninsula which separated the northern from the southern basins. The extent of this peninsula varied considerably during the different epochs of deposition. The area now covered by the

Santa Monica Mountains was apparently part of an early positive block bordering the east–west trough mentioned above. To the north of this trough the region now occupied by the Santa Ynez Mountains constituted the westward extension of the old Tehachapi peninsula.

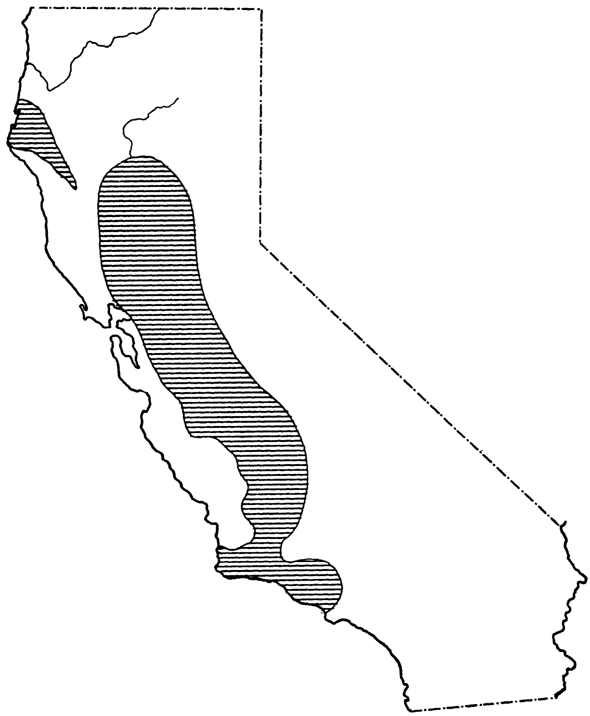

FIG. 3.—Meganos (Middle Eocene)

Some of these old positive areas were so persistent throughout the Tertiary time that they might well be given names, following, on a smaller scale, the example of Schuchert in his *Paleogeography of North America.* Certain of these positive and negative areas have been persistent throughout all Tertiary time, while others were formed at a later date. Also, it is worthy of note that the old positive and negative areas had the same trend as the present mountain ranges.

OLIGOCENE

Accumulated evidence appears to show that there were at least two distinct epochs of deposition on the West Coast during the Oligocene. The two epochs are represented by the Molopophorus lincolnensis and Acila gettysburgensis zones of Dr. C. E. Weaver. They

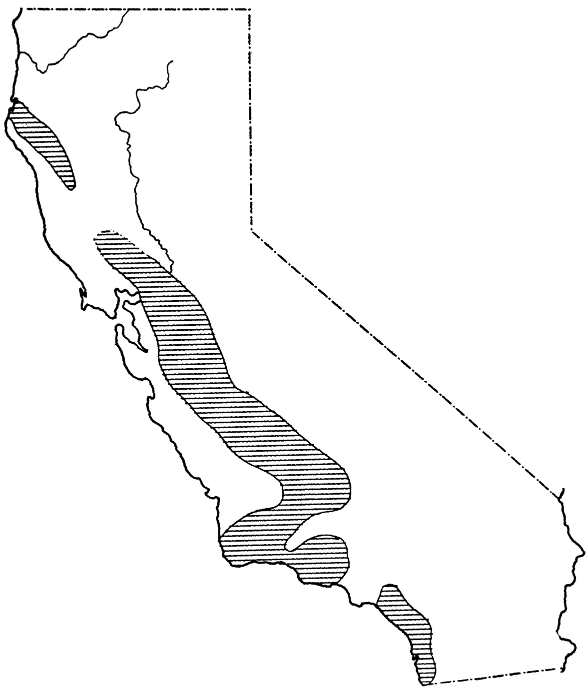

FIG. 4.—Tejon (Upper Eocene)

will be referred to as the Lincoln and San Lorenzo.[1] Recent field work of the writer has shown fairly conclusively that there were at least two distinct epochs of deposition in Oregon and Washington. He believes that this will prove to be the case in California when more detailed work on the stratigraphy of the Oligocene over wider areas has been completed. It is certain that the two faunas first

[1] C. E. Weaver, "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), pp. 1–21; "Preliminary Note on the Paleontology of Western Washington," *Wash. Geol. Surv. Bull., 15* (1912), pp. 1–80; "Tertiary Faunal Horizons of Western Washington," *Pub. Univ. Wash.*, Vol. I (1916), No. 1, pp. 1–67.

differentiated in Washington are also represented in the same sequence in California, and tentatively we may consider the Oligocene series as being made up of two distinct parts, referred to in the correlation table as the San Lorenzo series.

The aggregate thickness of the marine beds of the Upper and Lower Oligocene of the West Coast exceeds 10,000 feet. A large part of these sediments consists of shales and shaly sandstones.

Correlation.—The evidence for the correlation of the West Coast marine Oligocene deposits is indirect. No molluscan species or even apparently related forms have been recognized as common to the Oligocene of the West Coast and the Gulf province. The faunal evidence at hand seems to show that after the close of the Tejon epoch (Upper Eocene) there was no direct connection between the Atlantic and the Pacific Coast basins.

Dr. Ralph Arnold was the first to announce the presence of Oligocene in California. The type section of the San Lorenzo is in the Santa Cruz Mountains of the Santa Cruz Quadrangle, California. Dr. Arnold concluded that this formation is of Oligocene age because of its stratigraphic position between beds generally recognized as belonging to the Upper Eocene and Lower Miocene (Vaqueros) age. He observed that the fauna of the San Lorenzo appeared to have both Eocene and Miocene affinities.[1] Later studies of the faunas of the Lincoln and San Lorenzo horizons have borne out Arnold's original conclusions.[2] At the time Arnold did his work the Lincoln horizon had not been differentiated. The fauna of this horizon shows a much closer relationship to that of the Tejon (Upper Eocene) than to that of the Lower Miocene, while the fauna of the San Lorenzo horizon, equivalent to Weaver's Acila gettysburgensis zone, has a Miocene aspect, a fairly large number of the genera and species being common to the two.

[1] R. Arnold, "Tertiary and Quaternary Pectens of California," *U.S. Geol. Surv., Prof. Paper 47* (1906). J. C. Branner, F. G. Newsom, and R. Arnold, *U.S. Geol. Surv., Folio 163*, Santa Cruz Folio.

[2] B. L. Clark, "Occurrence of Oligocene in the Contra Costa Hills of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1915), No. 2, pp. 9–21; "San Lorenzo Series of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XI (1918), No. 2, pp. 45–234. B. L. Clark and R. Arnold, "Marine Oligocene of the West Coast of North America," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), pp. 297–308.

Climate.—The temperature conditions during the Oligocene time were fairly uniform along the West Coast as far north as Alaska. The waters of the Lower Oligocene, judging from the molluscan fauna, were subtropical to warm-temperate, while those of the Upper Oligocene sea were more temperate.[1] Thus the fauna of the San Lorenzo horizon (Upper Oligocene) is more closely related to that living off the coast of California, Oregon, and Washington at the present time than it is to that of the Lincoln.

Paleogeography.—The distribution of the Lower Oligocene deposits (the Lincoln horizon) (Fig. 5) corresponds closely to that of the Tejon (Upper Eocene). In California there was a long inland trough corresponding closely to, though somewhat wider than, the present Great Valley of California. The presence of great thicknesses of organic shales of the Kreyenhagen formation, from which the oil of the Coalinga field is derived, indicates that the deepest portion of the Lower Oligocene trough was along the western border of the present San Joaquin Valley.[2]

The distribution of the Upper Oligocene (San Lorenzo) is very different from that of the Lower Oligocene. In California there were two limited basins of deposition, one in middle California in the vicinity of San Francisco, and one in the region of the southern end of the San Joaquin Valley.

A fauna referred to the Oligocene which may be Upper Eocene.—The fauna of the Tejon (Upper Eocene) of the West Coast, as has already been stated, can probably be correlated with the upper Claiborne horizon of the Eocene of the Gulf province, but whether or not there is a fauna on the West Coast that is equivalent to the Jackson horizon of that province can only be proved by further detailed study.

The possibility of referring the Molopophorus lincolnensis zone, now considered Lower Oligocene, to the Jackson stage has been considered. Dr. C. E. Weaver has listed a number of species

[1] R. E. Dickerson, "Climate and Its Influence upon the Oligocene Faunas of the Pacific Coast," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 6, pp. 157–92.

[2] R. W. Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U.S. Geol. Surv. Bull. 603* (1915), pp. 74–78.

in the former horizon that are also found in the Tejon and the generic assemblages are notably similar. The Molopophorus lincolnensis zone, however, shows a closer relationship to the Acila gettysburgensis zone (Upper Oligocene) than to the Tejon, and subsequent work on the fauna of the Molopophorus lincolnensis

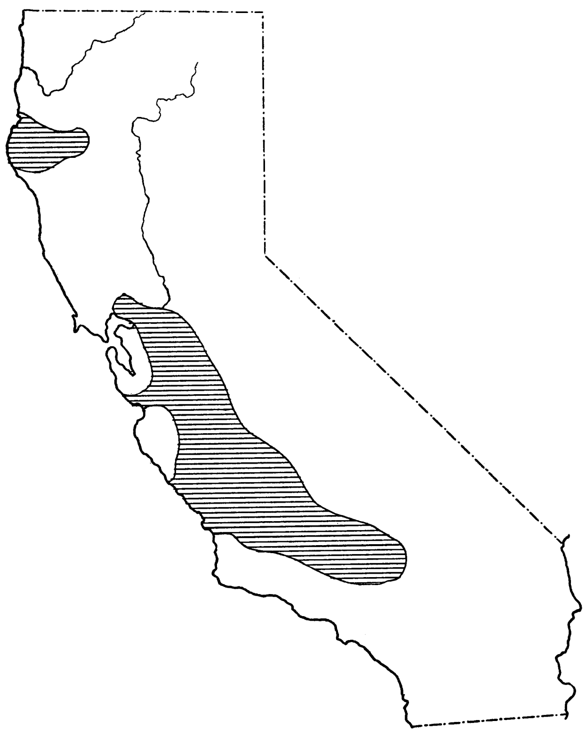

FIG. 5.—Lower Oligocene

zone has shown that there are fewer species common to the Tejon than Dr. Weaver supposed.[1]

There is still another fauna which may represent an Eocene stage higher than the Tejon. During the year 1912 a collection was made by Mr. F. M. Anderson and Mr. Bruce Martin, at that time curator and assistant curator in the department of paleontology of the California Academy of Sciences, from the Greise Ranch

[1] C. E. Weaver, "Preliminary Report on the Tertiary Paleontology of Western Washington," *Wash. Geol. Surv., Bull. 15* (1912), p. 16; "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), p. 167.

near the town of Vader in southern Washington. This collection came from beds unconformable on the Tejon, and below strata containing a typical Molopophorus lincolnensis fauna. The fauna was described by Dr. R. E. Dickerson and consisted of forty-eight species, of which thirty-six were considered new and thirteen were determined as common to the Molopophorus fauna.[1] The writer has had the opportunity of making larger collections from the Greise Ranch locality, and with Dr. G. D. Hanna, present curator of the department of paleontology of the California Academy of Sciences, has re-worked the fauna listed and described by Dr. Dickerson. The results of this work show quite conclusively that there is very little, if anything, in common between this fauna and that of the Molopophorus lincolnensis zone. The fauna at the present time consists of about seventy-five species and is very distinct from any other known fauna on the Pacific Coast. None of these species have been definitely determined as common to either the Tejon or the Molopophorus lincolnensis zone, and the stratigraphic position of the horizon renders it possible that these beds are equivalent to the Jackson of the Gulf province.

MIOCENE

The marine Miocene of the West Coast is divisible, both on the basis of stratigraphy and fauna, into two major series each of which contains minor horizons.

The portion of the geological section referable to the Monterey series (Lower-Middle Miocene) contains two fairly distinct faunas and two epochs of deposition, at least in certain areas of the state of California. The lower of these two divisions is the Vaqueros group, sometimes referred to as the "Turritella inezana" zone. The upper division of the Monterey series is herein referred to as the Temblor group and is represented by the fauna of the "Turritella ocoyana" zone. The deposits of the Vaqueros Sea covered a much more limited area than those of the Temblor, and have not been found in Oregon or Washington.

[1] R. E. Dickerson, "Climate and Its Influence upon the Oligocene Faunas of the Pacific Coast with Descriptions of Some New Species from the Molopophorus Lincolnensis Zone." *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 6, pp. 157–92.

The upper major Miocene division constitutes the San Pablo series, which is composed of three minor stratigraphic and faunal divisions, the Briones, Cierbo, and Santa Margarita groups. As will be brought out later, each one of these groups represents a distinct sequence of deposition and possesses a fairly distinctive fauna.

Monterey series.—Whether or not the Vaqueros and Temblor represent separate stratigraphic units has been the source of considerable disagreement in time past.[1] Nearly everyone, however, who has studied the fossils obtained from these beds has agreed that there are two fairly distinct, though closely related, faunas, one the fauna of the Turritella inezana zone, the other that of the Turritella ocoyana zone.

Recent stratigraphic and paleontological work, the results of which are still unpublished,[2] appears to show that at certain localities in California there were crustal movements of considerable magnitude between the deposition of the Vaqueros and the Temblor. The proper valuation of this hiatus is, in the writer's mind, still an open question. The faunas appear to be fairly closely related, and because of the obscure stratigraphic relations at various localities and the general similarity of the faunas the groups have usually been thrown together. The United States Geological Survey, in its more recent publications on Coast Range geology, applies the name "Monterey group" to these deposits, but the writer considers the Monterey a "series" because, at least in certain localities, it is composed of two epochs of deposition, the Vaqueros and the Temblor.

Stratigraphic relations of the Monterey series to the Upper Oligocene.—There is no conclusive evidence that there were any great

[1] G. D. Louderback, "Monterey Series of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VII (1913), No. 10, pp. 177–241. F. M. Anderson, "Stratigraphic Study of the Mount Diablo Range of California," *Proc. Cal. Acad. Sci.*, Third Series, Vol. II (1905), No. 2, pp. 161–248. F. M. Anderson, "Further Study of the Mount Diablo Range of California," *Proc. Cal. Acad. Sci.* Fourth Series, Vol. III.

[2] Mapping by Dr. Kew of the United States Geological Survey shows an important unconformity in southern California between the Temblor and the Vaqueros. Mr. Wayne Loel, formerly of Leland Stanford University, is working on a monograph of the Vaqueros. He believes that the faunas of the Temblor and the Vaqueros represent two distinct horizons.

crustal movements just previous to the deposition of the Vaqueros. However, that there was an important hiatus following the deposition of the San Lorenzo is brought out by a comparison of the San Lorenzo and Vaqueros faunas. Very few of the species of the San Lorenzo (Upper Oligocene) have been found in the Vaqueros, while a very large percentage of the species of the latter horizon are common to the Temblor. It is this great faunal change between the San Lorenzo and Vaqueros that is most significant and indicative of one of the major breaks.[1]

Correlation of the Temblor and Vaqueros.—As in the case of the Oligocene, very little direct evidence has been obtained for the correlation, on the basis of the invertebrates, of the divisions of the Monterey series with the Lower-Middle Miocene of the eastern province and Europe. These deposits of the Monterey series were first referred to the Miocene by Conrad[2] as early as 1837. This determination was made chiefly on the general similarity of the generic assemblages to the faunas of the Atlantic Coast Miocene. Following Conrad, the beds here referred to the Monterey series were determined by Whitney and Gabb, both of the old California State Geological Survey, as Miocene. No attempt was made by these pioneers to recognize any subdivisions in the Miocene. Beds now recognized as Upper Miocene (San Pablo) were called Pliocene by Whitney and Gabb[3].

The first announcement of a correlation which gave a fairly definite position to the Temblor group appeared in a paper by Professor J. C. Merriam, entitled "Tertiary Vertebrate Faunas of the North Coalinga Region of California."[4] Previously the Temblor had been referred by some geologists to the Lower Miocene and by others to the Oligocene. In the region of North Coalinga

[1] B. L. Clark, "San Lorenzo Series of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XI (1918), No. 2, p. 105.

[2] T. A. Conrad, "Fossils from Northwestern America," *Geol. U.S. Ex. Exped.*, Vol. I (1849), App., pp. 723–29, Pls. 17–20; *Proc. Acad. Nat. Sci. Phila.*, Vol. VII (1837), p. 441.

[3] W. M. Gabb, *California Geological Survey: Palaeontology*, Vols. I and II (1864–69).

[4] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Trans. Am. Phil. Soc.*, New Series, Vol. XXII (1915), Part III, pp. 1–44.

the land formation locally known as the Big Blue was intercalated with beds of Temblor age from which good marine faunas have been obtained.[1] The Big Blue was first considered by Arnold and Anderson[2] as a part of the Santa Margarita (Upper Miocene). Later mapping, however, showed that it is more closely connected to the Temblor (the so-called Vaqueros) than to the Santa Margarita of that section.

In describing the fauna obtained from the Big Blue, Merriam says:

> In terms of the vertebrate series of Western North America the fauna of the Merychippus zone in the north Coalinga region is clearly later than lower Miocene and not later than upper Miocene. The fact that the Big Blue comes in a section where the Temblor deposits are very thin, and we think are only the top of that section, makes it seem reasonable to believe that the Temblor deposits as a whole belong to the middle Miocene rather than to a part of the upper Miocene.[3]

A clue to the age of the Vaqueros deposits was obtained very recently by the discovery of land-laid deposits near the south end of the San Joaquin Valley which are intercalated with marine deposits of the Vaqueros age. Beds containing a Vaqueros fauna are found immediately below these land-laid beds, and the marine beds immediately above are believed to represent the same horizon. The announcement of the discovery of a vertebrate fauna obtained from these land-laid beds associated with the Vaqueros was recently made by Dr. Chester Stock.[4] These land-laid deposits, referred to as the Tecuja beds, were tentatively correlated by Dr. Stock with the John Day horizon of Oregon. He reports the presence of the genus *Hypertragulus*, a form related to the early camels and deer. *Hypertragulus* occurs both in the Upper Oligocene and the Lower Miocene, but the species from the Tecuja beds seems more

[1] The beds mapped as Vaqueros in the Coalinga field by the United States Geological Survey belong to the Temblor horizon rather than to the Vaqueros.

[2] R. Arnold and R. Anderson, "Geology and Oil Resources of the Coalinga District of California," *U.S. Geol. Surv., Bull. 396* (1909), p. 90.

[3] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Trans. Am. Phil. Soc.*, New Series, Vol. XXII (1915), Part III, p. 20.

[4] Chester Stock, "An Early Tertiary Vertebrate Fauna from the Southern Coast Ranges of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XII (1920), No. 4, pp. 267–76.

closely related to the John Day (Upper Oligocene) form than to that found in the lower Rosebud (Lower Miocene) of the Great Basin region. While Dr. Stock has indicated the relationships of of the Tecuja vertebrate fauna to that of the John Day, he has also stated that it may occupy a position in the Tertiary transitional between Oligocene and Miocene. It seems to the writer that the stratigraphic and paleontologic evidence favors the Lower Miocene age of these beds rather than the Upper Oligocene. The most important evidence in favor of this last conclusion is that the invertebrate fauna of the Vaqueros as already stated, is very closely related to that of the Temblor, a very large percentage of the species being common to the two faunas. Some of the forms listed are types of considerable ornamentation and complexity and are known to have a fairly short geological range. On the other hand, the known fauna of the Vaqueros is very different from the known fauna of the San Lorenzo, and there is here a much greater faunal break than between the Vaqueros and the Temblor. In the section at the south end of the San Joaquin Valley, where the Tecuja beds occur, the Vaqueros rests directly and unconformably upon the San Lorenzo.

Climate.—The conditions of temperature during the Vaqueros and Temblor epoch seem to have been between warm-temperate and subtropical. The generic assemblages of the two horizons are very similar. The large lyropectens and dosinias are found in both, and a fairly high percentage of the species are common to the two horizons. This close relationship of the faunas indicates a similar temperature of the waters.

One of the puzzling problems in connection with the origin of the Temblor deposits is the great thickness of organic shales that is found all along the coast of California and especially in the southern part of the state. In some localities these organic shales, a very large proportion of which are composed of the frustules of marine diatoms, have a thickness exceeding 5,000 feet. Diatomaceous oozes in any considerable quantity are now only found in Arctic and Antarctic waters, and from this we might judge that these shales were deposited in cold water. However, the fossil molluscan faunas found in these shales, or closely associated with them,

indicate a moderate temperature. Dr. J. C. Branner, in a paper read before the Cordilleran Section of the Geological Society of America, suggested an explanation of this apparent disagreement between the floral and faunal evidence.[1] The great thickness of diatomaceous shales in southern California is to be explained by the hypothesis that cold currents carried the diatoms southward along the coast and finally into the partially land-locked basins of southern California where they were killed by the change in temperature. The continuous supply from the north resulted in great thicknesses of deposits composed largely of the tests of these minute plants. This hypothesis may also be an explanation of the origin of the diatomaceous shales of the Oligocene and Upper Miocene.

Paleogeography.—The Temblor deposits have much wider distribution than those of the Vaqueros (Figs. 6 and 7) and are found on the eastern as well as the western side of the Coast ranges. On the eastern side from the vicinity of Coalinga northward these deposits are composed of coarse clastics, while to the west organic shales cover the larger part of the section. The comparison of the area covered by this sea with that which existed during Lower Oligocene time (when the Kreyenhagen shales were deposited), (Fig. 4) shows a marked change. As has already been stated, the Oligocene sediments were deposited in an inland north–south trough very similar to that which existed during the Eocene. The deepest part of the Oligocene trough was on the eastern side of the present Coast ranges, a very large part of the western side at that time apparently having been subject to erosion. On the other hand, the deepest part of the Temblor sea was on the western side of the present Coast ranges; the areas which had been land during the Oligocene were inundated, while to the east, where the Oligocene trough had been deepest, the strand-line deposits indicate shallow water conditions. At this time the interior Diablo range probably formed an archipelago of islands.

San Pablo series.—The San Pablo series is recognized as the second major division of the Miocene. Like the San Lorenzo and

[1] J. C. Branner, "Influence of Wind on the Accumulation of Oil-bearing Rocks," *Proc. Thirteenth Ann. Meeting of the Cordilleran Section of the Geol. Soc. of Am., Bull. Geol. Soc. Am.*, Vol. XXIV (1913), pp. 94–95.

Monterey series, the San Pablo is divisible into minor units on the basis of stratigraphy and fauna. The faunal changes and disconformable relationships of the beds indicate that the sea advanced and retreated three times in middle California, during this period. It is only in middle California that we find the complete sequence of the Upper Miocene series. The two lower divisions of the San

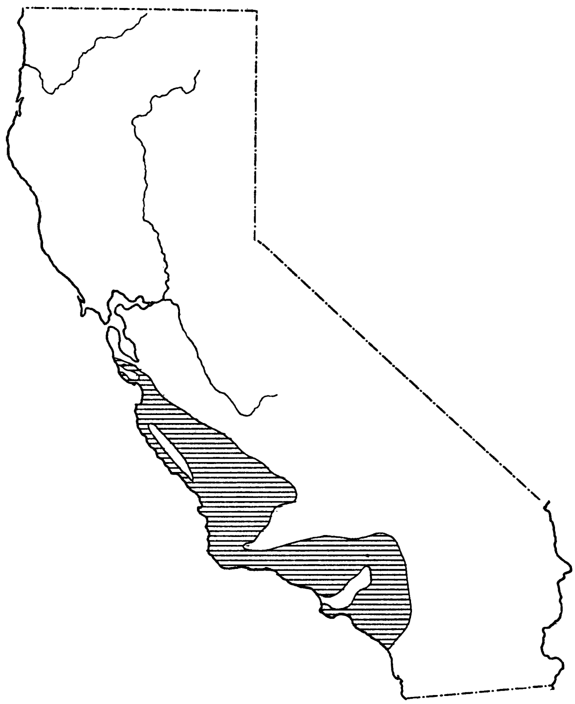

FIG. 6.—Vaqueros (lower Monterey, Miocene)

Pablo series, the Briones and Cierbo groups,[1] have been recognized only in the general region of San Francisco Bay.

Stratigraphic relationships.—In certain sections immediately east of or in the Salinas Valley, a distance of not more than 100 miles

[1] The use of the term San Pablo for the Upper Miocene series of deposits on the West Coast makes it necessary to dispense with the term San Pablo within the group. The name Cierbo is therefore used in this paper in referring to the middle group of the San Pablo series. The type section of the Cierbo is in the south side of the Canada del Cierbo near Carquinez straits. Santa Margarita is a name in common use for the upper portion of the section in the southern part of the state of California and will be applied as a general name for the upper member of the San Pablo series.

from the San Francisco Bay area, we find evidences of crustal movements between the Temblor and the Santa Margarita which have been described as mountain-making. In the Salinas Valley region it is not uncommon to find the difference in dip between the Temblor and the Santa Margarita as much as 30° to 90°, together

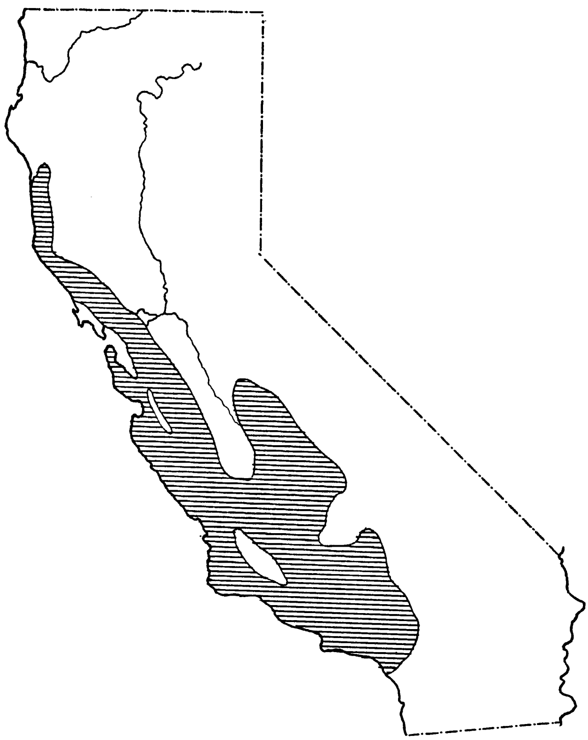

FIG. 7.—Temblor (upper Monterey, Miocene)

with marked difference in strike. Dr. Arnold, in describing the movements that caused this unconformity, says:

One of the most widespread and important periods of diastrophism in the Tertiary history of the Pacific Coast was that immediately following the deposition of the Monterey or lower middle Miocene. Its effects are visible from Puget Sound to southern California It is marked as much by readjustment, by local faulting and folding as by general movements of elevation and subsidence. In some regions the folding and faulting were intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. In other regions low broad folds were formed during the

post-Monterey disturbance, and the strata were not upheaved to a great altitude. Faulting on a most magnificent scale took place along the earthquake rift and certain other fault-zones, especially that in the Salinas Valley, and along these lines of displacement, masses of granitic rocks, which during the preceding epoch had been subject to little or no erosion, were suddenly thrust upward and left exposed to the ravages of streams that assumed the proportions of torrents in certain regions, as for instance adjacent to the Carrizo Plain in south-central California. The post-Monterey diastrophic movements in the Puget Sound province also produced sharp relief as is evidenced by the coarse sediments immediately following the disturbance. The localization of movements during the period is exemplified at numerous localities in the Coast Ranges.

Throughout much of the coastal belt, and probably likewise in the interior, great volcanic activity took place during the middle Miocene, this being the last epoch of volcanism in the Coast Ranges, south of San Francisco Bay.[1]

It is interesting to note that only a comparatively short distance to the east of the southern Salinas Valley area, where the great unconformity between the Temblor and the Santa Margarita deposits is best seen, it has been very difficult to find the line separating these two horizons. Both the Santa Margarita and Temblor deposits to the southwest of the San Joaquin Valley are composed of organic shales, and in consequence of the difficulty in separating the two horizons the United States Geological Survey has applied the name Maricopa shale to the deposits as a whole.[2] No marked stratigraphic break has been found in middle California between the deposits of the lower San Pablo series (Briones group) and those representing the Temblor. Here the beds of these two horizons are parallel, the chief basis for making the separation being irregular contacts and the difference between the faunas. In middle California, therefore, we have no evidence of crustal movements immediately after the deposition of the Temblor.

Correlation.—Direct evidence for the correlation of the San Pablo series with the eastern and European sections is lacking. The writer has presented the evidence for the correlation of this

[1] R. Arnold, "The Environment of the Tertiary Faunas of the Pacific Coast of the United States," in Willis *et al.*, *Outlines of Geology* (1910), p. 241.

[2] R. W. Pack, "Geology and Oil Resources: Sunset-Midway Oil Field, California," *U.S. Geol. Surv., Prof. Paper 116* (1920), p. 35.

group in a former paper. The correlation is based upon an analysis of the molluscan fauna by the percentage method and the evidence afforded by the occurrence of vertebrates in beds immediately above and below the San Pablo. The following quotations are taken from the above-mentioned paper:

The percentage of Recent molluscan species in the San Pablo of middle California as listed by the writer is 23 plus; as based upon the gastropods the percentage is only 11 per cent. If we use the percentages as applied to the east coast Neocene and if we can rely upon the equal refinement in the determination of the species, the San Pablo may be considered to be upper Miocene in age, possibly lower Pliocene.

Probably the best evidence showing the age of the uppermost beds of the San Pablo of middle California comes from vertebrate material obtained in the fresh-water beds which in middle California overlie unconformably the San Pablo group. This material was described by Professor J. C. Merriam in his paper "Vertebrate Fauna of the Orinda and the Siesta Beds in middle California."[1] His conclusions as to the age of these beds as shown by the vertebrates are as follows: "The mammalian remains known from both the Orindan and Siestan up to the present time all represent forms such as might be expected in the late Miocene or in the earliest Pliocene, but it will be necessary both to have better material from the Orindan and Siestan and to have well known faunas of western Miocene and Pliocene for comparison before the last word on the age determination can be pronounced.

"Considering the indefiniteness of all the factors concerned, one would not seem justified in being more definite than to state that the Orindan and Siestan faunas are near a late Miocene stage. When the faunas of the two formations are better known, it may appear that more than one stage is represented."[2]

The reader will remember from the discussion of the age of the Temblor that the vertebrate fauna obtained from the Big Blue formation, which is apparently intercalated with the Temblor deposits in the north Coalinga region, was determined by Dr. J. C. Merriam as being not earlier than Middle Miocene. In this same section the Santa Margarita formation is found unconformably above the Big Blue and marine Temblor beds. Also, as will be brought out in the discussion of the Pliocene, a Lower Pliocene vertebrate fauna was found in land-laid beds which rest unconform-

[1] J. C. Merriam, "Vertebrate Fauna of the Orindan and Siestan Beds in Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VII (1913), No. 19, pp. 373–85.

[2] B. L. Clark, "The Fauna of the San Pablo Group of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1915), No. 22, p. 439–42.

ably upon the top of the Santa Margarita. Thus it would seem that if we can trust the correlation on the basis of the vertebrates, there can be very little doubt as to the age of the Santa Margarita group which comes between two vertebrate horizons, one not earlier than Middle Miocene, the other not later than Lower Pliocene.

Climate.—The paleontological evidence seems to show that, beginning with the Upper Miocene, there was a temperature differentiation on the West Coast that was even more marked than that existing today.

The Briones and Cierbo groups (lower and middle San Pablo) are not found in southern California, and because of their limited distribution give us very little evidence of temperature differentiation.

The fauna obtained from the Santa Margarita (upper San Pablo) in middle California may be regarded as approximately warm-temperate, and if it were now living it would probably not be found south of Santa Barbara County. This conclusion is based upon the large percentage of recent species found in the faunal assemblage and common to the fauna now found living between San Francisco Bay and Santa Barbara. The presence of certain recent species and the absence of certain genera found at northern localities indicate that the Santa Margarita horizon in southern California represents a warmer facies than that found in middle California. There is, however, a sufficient number of distinctive species common to the two horizons to establish their correlation, though the faunas are on the whole very different.

The fauna of the Montesano formation of Washington, described by Dr. C. E. Weaver,[1] is apparently Upper Miocene in age, but just what part of the San Pablo series it represents has not been established. This fauna, judging from the recent genera and species in the assemblage, is boreal and consequently very different from that of the San Pablo. If the correlation of the Montesano formation with the San Pablo series is correct, there was at that time a temperature differentiation comparable to that found between the recent faunas of middle California and Alaska.

[1] C. E. Weaver, "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), pp. 1–327.

Paleogeography.—The sediments of the Briones and Cierbo groups were deposited in a limited arm of the sea confined to the San Francisco Bay region (Figs. 8 and 9). Where all the groups of the San Pablo series are present, erosion contacts are found separating them.

With the opening of the Santa Margarita there was a great inundation, somewhat comparable to that of the Temblor, though

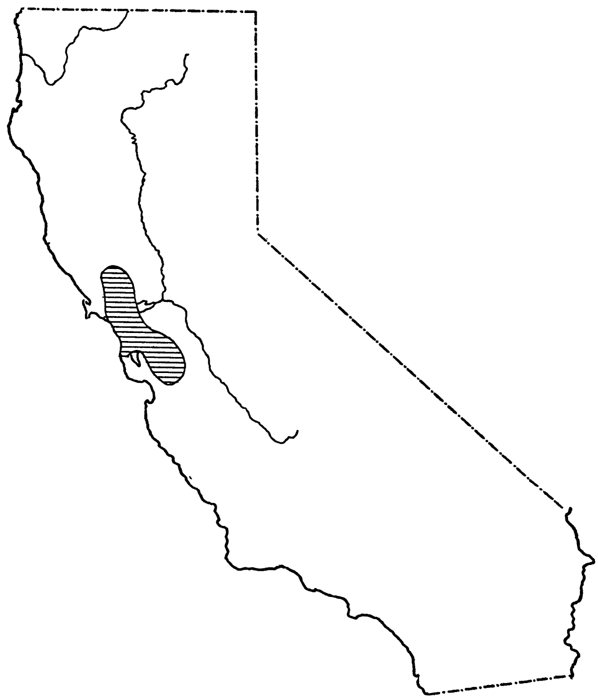

FIG. 8.—Briones (lower San Pablo, Miocene)

the basins of the former were more local. Beds of Santa Margarita age are found from a little north of San Francisco to the region just north of Los Angeles (Fig. 10). The deposits are found on both the eastern and the western sides of the Coast ranges, and over large areas to the south of San Francisco these deposits are composed very largely of organic shales of considerable thickness.

PLIOCENE

The marine Pliocene of the West Coast as now recognized is divisible into at least three distinct horizons: the Jacalitos, the Merced, and the Saugus. Continental deposits are found in different parts of the Coast ranges representing all three of these horizons, and in some instances to which reference has already been made these continental deposits are found closely associated with the marine beds.

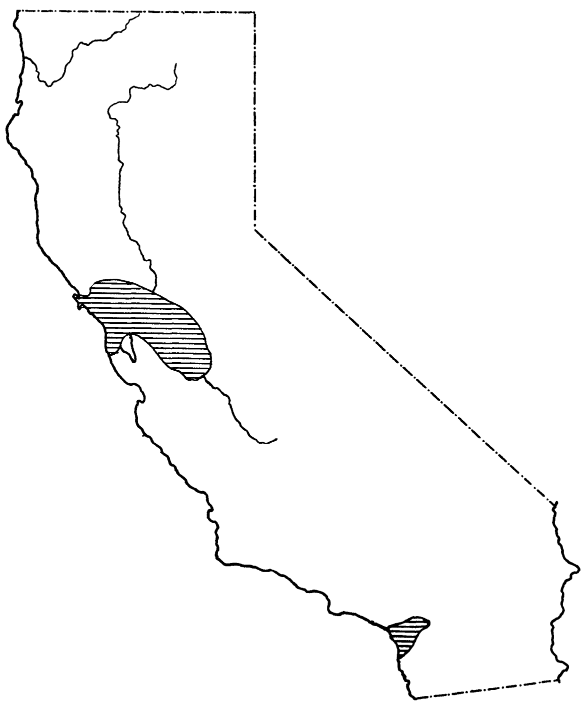

FIG. 9.—Cierbo (middle San Pablo, Miocene)

Stratigraphic relationship of the Pliocene and Upper Miocene.— No evidence of folding between the beds of the Santa Margarita (Upper Miocene) and the Jacalitos (Lower Pliocene) has been obtained in southern California, though good erosion contacts are found separating them and the faunas are on the whole very different. In the vicinity of Mount Diablo, just to the east of the San Francisco region, the Santa Margarita beds were folded before the

Lower Pliocene deposits were laid down. The Lower Pliocene in this region is composed of the Pinole tuff and the Orinda formation which are of continental origin.

Faunal relationships of the Pliocene.—Dr. Nomland's study of the faunas of the Jacalitos ("lower Etchegoin") and Santa Margarita has shown that they are very distinct, and that the hiatus between them was more than local.[1] None of the highly ornamented gastropods, pelecypods, or echinoids has been found common to the two, and the percentage of recent species in the Santa Margarita is much less than that in the Jacalitos (lower Etchegoin) of Nomland.

An unconformity has been found in the Fernando series in the region just north of Los Angeles which is probably the largest and most important stratigraphic break in the West Coast marine Pliocene.[2] Over a fairly large area in that region there is a marked difference in dip and strike between the lower and middle Fernando, now referred to the Pico formation by the United States Geological Survey, and what has previously been referred to as the upper Fernando.[3] The beds of this upper horizon contain a very large percentage of recent species. The Geological Survey proposes to use the name "Saugus formation" for the upper Fernando section. It is herein referred to as the Saugus group. The faunal break between the Saugus and the Pico indicates a great lapse of time. Indeed, the difference is so great that the question may be raised as to whether the Saugus does not belong to the Pleistocene

[1] J. O. Nomland, "Fauna of the Lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916), No. 14, pp. 199–214; "Fauna of the Santa Margarita Beds in the North Coalinga Region of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. X (1917), No. 18, pp. 293–326.

[2] G. H. Eldridge, and R. Arnold, "Santa Clara Valley, Puente Hills and Los Angeles Oil Districts of California," *U.S. Geol. Surv., Bull. 309* (1907), pp. 1–259. R. Arnold and R. Anderson, "Geology and Oil Resources of the Santa Maria District, California," *U.S. Geol. Surv., Bull. 322* (1907), pp. 1–157. W. S. W. Kew, "Structure and Oil Resources of the Simi Valley, Southern California," *U.S. Geol. Surv., Bull. 691 M* (1919), pp. 323–55.

[3] A paper by Dr. W. S. W. Kew of the United States Geological Survey is now in press in which the Fernando is considered a group composed of the Pico and Saugus formations separated by an unconformity.

rather than to the Pliocene. If so, the West Coast Pleistocene formations have been generally folded.

Correlation.—There has been considerable confusion in times past as to the proper sequence of the Pliocene. The difficulties appear to have been due to two factors: first, the basins of deposition during the Pliocene were more local and isolated than they had

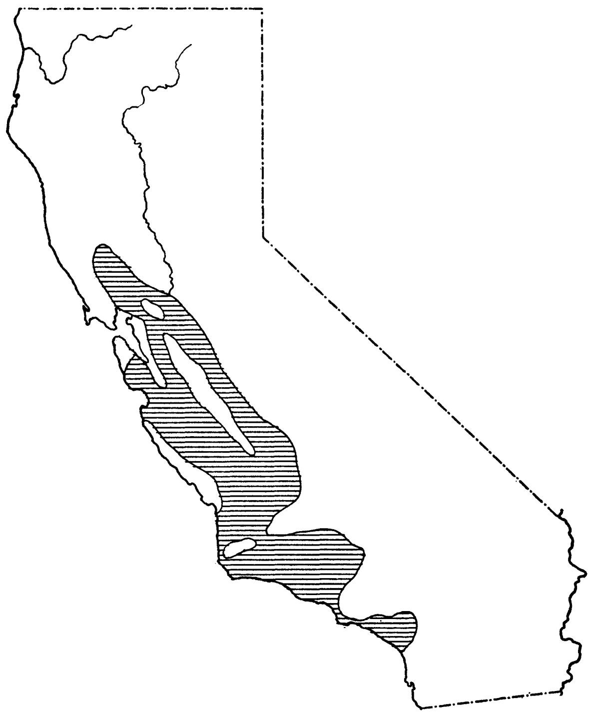

FIG. 10.—Santa Margarita (upper San Pablo, Miocene)

been during previous periods; and second, conditions of temperature varied from one locality to another. These factors were undoubtedly the cause of the great differences found between the faunas of the various provinces; however, the latter factor, temperature, was the most important. The great confusion as to the proper sequence of the Pliocene formations is reflected in the numerous names which have been given to them. Beginning

in Oregon, we have the "Empire" formation;[1] in northern California, the "Wildcat";[2] in the region of San Francisco Bay, the "Merced";[3] and a little to the south of this, in Santa Cruz County, is the "Purissima."[4] Still farther to the south are the "Jacalitos" and "Etchegoin" formations in the Coalinga region;[5] the "Pico" and "Saugus" formations of the Fernando group[6] in the Ventura region and the "San Pedro"[7] and "San Diego" Pliocene deposits on the southern California coast. The "Purissima," "Jacalitos," "Etchegoin," and "lower Fernando" have in the past been referred to the Upper Miocene and correlated with the San Pablo of middle California.

During the last few years our ideas of the sequence of these various formations have been very radically revised as the result of more detailed studies of vertebrate and invertebrate faunas. The writer's study of the San Pablo series convinced him that the faunas of that series belong to an older horizon than those of the Jacalitos-Etchegoin, Purissima, and Pico, and that the percentage of recent species in the latter beds indicate Pliocene age. Later work by Dr. Nomland on the Jacalitos and Etchegoin of the Coalinga region corroborated these conclusions.

[1] W. H. Dall, "The Miocene of Astoria and Coos Bay, Oregon," *U.S. Geol. Surv., Prof. Paper 59* (1909), pp. 1–261.

[2] A. C. Lawson, "The Geomorphogeny of the Coast of Northern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. I, No. 8 (1894), pp. 24–272. Bruce Martin, "Pliocene of Middle and Northern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916), No. 15, pp. 215–59.

[3] A. C. Lawson, *U.S. Geol. Surv., Folio 193*, San Francisco Folio; "Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. I, No. 4 (1893), pp. 115–60.

[4] J. C. Branner, F. G. Newsom, and R. Arnold, *U.S. Geol. Surv., Folio 163*, Santa Cruz Folio.

[5] J. O. Nomland, "Fauna of the Lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916) No. 14, pp. 199–214; "Etchegoin Pliocene of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. X (1917), No. 14, pp. 191–254. R. Arnold, "Palaeontology of the Coalinga District, California," *U.S. Geol. Surv., Bull. 396* (1909), pp. 5–169.

[6] W. A. English, "Fernando Group near Newhall California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1914), No. 8, pp. 203–8.

[7] R. Arnold, "Palaeontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Cal. Acad. Sci., Memoir III* (1903).

The most conclusive evidence of the Pliocene age of the Jacalitos and Etchegoin was the discovery of fossil land vertebrates in these formations in the Coalinga district. These vertebrate remains were obtained from three distinct horizons: one in what has been mapped as Jacalitos, another in the middle of the type section of the Etchegoin, and the third at the top of the Etchegoin. Professor J. C. Merriam, to whom this material was referred for study, has determined these faunas to be of Pliocene age. Merriam referred to the lowest fauna, that of the Neohipparion zone, as being not older than Lower Pliocene.[1] The next horizon is fairly well up in the Pliocene, and the fauna from the upper Etchegoin is referred to the Upper Pliocene.

It is interesting to note that stratigraphically above the Pliohippus proversus beds of Merriam (uppermost Pliocene), in the above-mentioned section, there are several thousand feet of land-laid deposits which are folded and are older than the Pleistocene terraces of that region. No evidence of the exact age of these beds has been obtained, but it is suggested that they may be the land-laid equivalent of the Saugus of that vicinity.

Climate.—One of the most interesting results of the study of the invertebrate faunas of the Pliocene is the evidence they give of temperature differentiation. The fauna from the Wildcat and Merced of northern and middle California is essentially boreal in character. In southern California the Pliocene is for the most part represented by a fairly warm-temperate fauna. These two faunas, the boreal and the warm-temperate, have very little in common, and consequently it was a long time before their contemporaneity was recognized. The solution of the problem was obtained from the fauna of an intermediate area. The fauna of the type section of the Purissima in the Santa Cruz Mountains of California is in part warm-temperate and in part boreal, and certain species very common in the north, some of which are fairly highly ornamented forms, were found in this section.

Paleogeography.—It was noted in the first paragraph, under the discussion of the factors causing the differentiation of faunas of

[1] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Amer. Phil. Soc. Trans.*, N.S. Vol. XII, Pl. III (1915), pp. 26–43.

the Pliocene, that the basins of deposition were local. Crustal movements appear to have been more frequent during the Pliocene than during the other periods of the Tertiary, and we may therefore expect to find a large number of stratigraphic breaks which do not represent any very great time break. At the opening of the Pliocene the Jacalitos sea was much more limited than the seas of

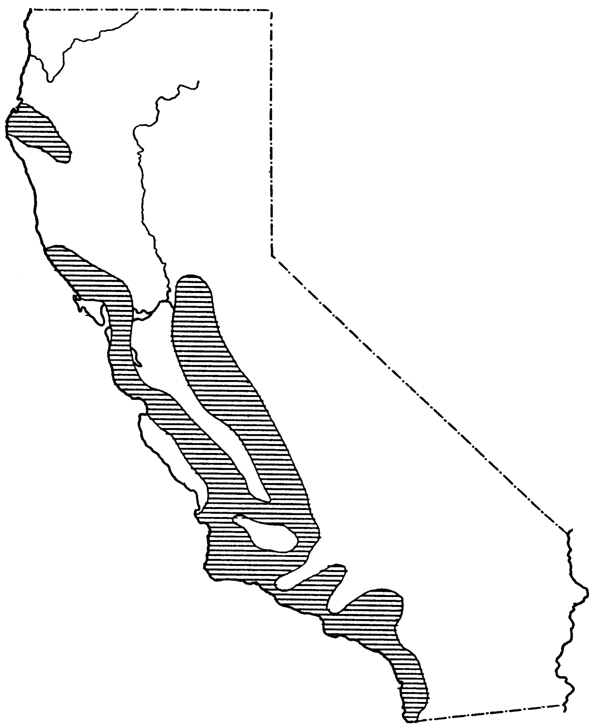

FIG. 11.—Merced (Middle Pliocene)

the Middle or possibly the Upper Pliocene, and the principal localities where deposition took place were probably in the region of the southern and western side of the San Joaquin Valley and the southern part of the Salinas Valley. This sea was probably connected with the ocean in the vicinity of the upper Salinas Valley.

With the opening of the middle Pliocene a great change had taken place. The sea transgressed over wide areas to the north. Areas which had previously been subject to erosion were covered.

This great incursion is referred to here as the Merced sea and represents the time of deposition of the Purissima, Etchegoin, and Jacalitos (Fig. 11). The condition was similar to that which existed in the Upper Miocene, when there were restricted basins at the opening of the period, a great incursion during the later part of the period, and then a retreat shown by widespread unconformities.

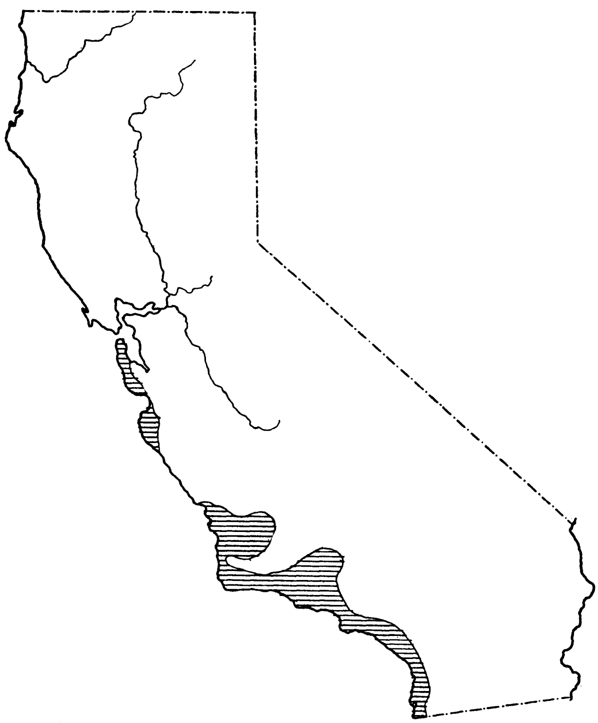

FIG. 12.—Saugus (Upper Pliocene)

The Saugus formation, of which little is known, appears to have been formed after the folding and consequent retreat of the sea from the great inland basins in the San Joaquin and Salinas Valley districts. The Saugus beds are largely confined to the coast, but in the Ventura district an embayment extended a considerable distance inland (Fig. 12).

The Pliocene period was followed by great crustal movements which folded the formations in great anticlines and synclines, some

of which were overturned. In certain localities the Cretaceous has been thrust over the younger formations. Though this great period of crustal movement had its culmination at the close of Saugus time, it was well under way even prior to the deposition of these beds. In the past geologists have generally assumed that the division between the Pliocene and Pleistocene occurs after this great folding, that is, at the end of Saugus time. But the very large percentage of the Recent species in the Saugus suggests that the group may possibly be of Pleistocene age, and therefore a large part of the folding which created the Coast ranges may have taken place during Pleistocene time.

MARINE TE

	Standard Section of the California Coast Ranges		Mount Diablo Region: North of Mount Diablo	Mount Diablo Region: West of Mount Diablo	Santa Cruz Mountains	Salinas Valle District
Pliocene	SAUGUS			200′ gravel, sands, clays	SANTA CLARA* 500′ gravel, sands, clays	PASO ROBLES* 1000′ clays, sands, con
	MERCED		ORINDAN* 1000′ PINOLE TUFF* 200′	SIESTAN* *Pliohippus* ORINDAN* 2000–6000′ PINOLE TUFF* 200–1000′	MERCED PURISSIMA Cold Water Fauna *Cardium meekianum* Gabb *Chione securis* Shumard *Nassa moraniana* Martin *Chrysodomus stantoni* Arnold *Dendraster oregonensis* Clark *Dendroster interlineatus* Stimpson Warm Water Fauna *Pecten healyi* Arnold *Pecten oweni* Arnold *Dendraster gibbsi* Rémond *Dendraster perrini* Weaver 5400′ ss and sh	ETCHEGOIN *Pecten healyi* Ar *Pecten coalingen* Arnold *Pecten etchegoin* Anderson *Thais kettleman* Arnold *Turris coalingen* Arnold *Calliostoma kerr* Arnold *Dendraster gibbs* Rémond ? ? JACALITOS *Pecten terminus* *Dosinia jacalito* Arnold *Astrodapsis j sensis* Arnold Jacalitos–Etch 2000′
Upper Miocene	San Pablo Series	SANTA MARGARITA	SANTA MARGARITA *Astrodapsis tumidus* Rémond *Pecten raymondi* Clark *Trophon ponderosum* Gabb	SANTA MARGARITA *Pecten crassicardo* Conrad *Pecten raymondi* Clark *Pecten pabloensis* Conrad *Astrodapsis tumidus* Rémond *Astrodapsis whitneyii* Rémond 1250′	SANTA MARGARITA *Astrodopsis whitneyii* Rémond *Astrodapsis antiselli* Conrad 300′ ss and sh	SANTA MARGARI *Pecten crassicardo* C *Pecten raymondi* Cla *Ostrea titan* Conrad *Astrodapsis tumidus* Rémond *Astrodapsis antisell* Conrad *Astrodapsis ornatus* 3000′ ss
		CIERBO	CIERBO *Dosinia merriami* Clark *Modiolus gabbi* Clark *Calyptraea diabloensis* Clark *Scutella gabbi* Rémond Santa Margarita and Cierbo 600′ ss and sh	CIERBO *Pecten crassicardo* Conrad *Pecten raymondi* Clark *Pecten weaveri* Clark *Scutella gabbi* Rémond *Astrodapsis cierboensis* Kew 1300′ congl and ss		
		BRIONES		BRIONES *Pecten raymondi* Clark, n. var. *Pecten tolmai* Hall & Ambrose *Astrodapsis brewerianus* Rémond *Acanthina sinuatum* (Gabb) 2300′ ss		
Lower Miocene	Monterey Series	Undifferentiated "Monterey Shale": TEMBLOR		TEMBLOR "Rodeo Shale" "Hambre Sandstone" "Tice Shale" "Oursan Sandstone" "Claremont Shale" "Sobrante Sandstone" *Pecten andersoni* Arnold *Ostrea titan* n. var.? *Agasoma barkerianum* Cooper *Turritella ocoyana* Conrad *Pecten peckhami* Gabb 3000′ ss and sh	TEMBLOR "Monterey Shale" *Pecten andersoni* Arnold *Agasoma santacruzana* Arnold *Turritella ocoyana* Conrad *Pecten peckhami* Gabb 5000′ organic shale	TEMBLOR "Salinas Shale *Pecten andersoni* A *Pecten peckhami* Ga *Pecten discus* Conra *Turritella ocoyana* 5000–7000′ organic shales
		VAQUEROS			VAQUEROS *Turritella inezana* Conrad 2700′ ss, sh, and congl	VAQUEROS *Turritella inezana* C *Pecten magnolia* Co *Pecten perrini* Arno 500′ ss
			KIRKER	CONCORD	SAN LORENZO	SAN LORENZO

INE TERTIARY OF THE WEST COAST

LINAS VALLEY DISTRICT	REGION OF COALINGA AND NORTH	MCKITTRICK AND SUNSET-MIDWAY DISTRICTS	SANTA MARIA AND SANTA YNEZ MOUNTAINS DISTRICTS	VENTURA DISTRICT: Santa Paula	VENTURA DISTRICT: Newhall	LOS ANGELES TO SANTA ANA MOUNTAINS: Generalized Section	GENERALIZED S OREGON, WASH AND NORTH CALI COAST RAN
ASO ROBLES* 1000′ s, sands, congl	TULARE* 3000′ clays, sands, gravel	PASO ROBLES* 2300′ sands, clays, gravel	SAUGUS *Pecten bellus* Conrad *Pecten hemphilli* Dall *Venericardia californica* Dall *Dendraster diegoensis* Kew (Fernando Group)	SAUGUS "Upper Fernando" *Pecten bellus* Conrad *Pecten hemphilli* Dall *Dendraster diegoensis* Kew *Crepidula princeps* Conrad		SAUGUS "Upper Fernando" *Pecten healyi* Arnold *Pecten caurinus* Gould *Pecten opuntia* Dall *Crepidula princeps* Conrad	UPPER PLIO
ETCHEGOIN *ten healyi* Arnold *ten coalingensis* Arnold *ten etchegoini* Anderson *ais kettlemanensis* Arnold *rris coalingensis* Arnold *lliostoma kerri* Arnold *ndraster gibbsi* Rémond	ETCHEGOIN 3500′ Pliohippus	ETCHEGOIN *Pecten healyi* Arnold *Pecten etchegoini* Anderson *Dendraster gibbsi* (Rémond) 3700′ sands, clays, gravels	PICO *Pecten oweni* Arnold *Pecten ashleyi* Arnold *Arca camuloensis* Osmont *Astrodapsis fernandoensis* Pack *Chrysodomus arnoldi* Rivers *Turris elsmerensis* English (Fernando Group) Fernando group 3000′ ss, sh, congl	PICO *Pecten oweni* Arnold *Pecten cerrosensis* Gabb *Chione elsmerensis* English *Chione fernandoensis* Arnold *Dosinia jacalitosensis* Arnold *Cancellaria elsmerensis* English *Astrodapsis fernandoensis* Pack Fernando group 5000–6000′ ss, sh, and congl		PICO *Pecten oweni* Arnold *Pecten wattsi* Arnold *Pecten hastatus* Sowerby *Pecten auburyi* Arnold *Ostrea veatchii* Gabb *Arca trilineata* Conrad 2000′ ss and sh	EMPIRE (of Orego 1000′ ss WILDCA (of Humboldt C 4600′ ss *Pecten coosensis* *Pecten caurinus* *Chione securis* S *Argobuccinum c* Dall *Dendraster orego* (Clark)
? ? JACALITOS *ten terminus* Arnold *sinia jacalitosensis* Arnold *trodapsis jacalitoensis* Arnold acalitos–Etchegoin 2000′	? ? ? JACALITOS *Pecten terminus* Arnold *Dosina jacalitosensis* Arnold *Astrodapsis jacalitosensis* Arnold 3600′						
NTA MARGARITA *crassicardo* Conrad *raymondi* Clark *titan* Conrad *apsis tumidus* ond *apsis antiselli* rad *apsis ornatus* Kew 3000′ ss	SANTA MARGARITA *Pecten raymondi* Clark *Chione semiplicata* Nomland *Turritella freya* Nomland *Astrodapsis coalingensis* Kew *Astrodapsis major* Kew 900′ ss	SANTA MARGARITA 900′ ss (Called "Maricopa Shales" by Pack)	SANTA MARGARITA *Pecten raymondi* Clark *Ostrea titan* Conrad *Astrodapsis tumidus* Rémond		SANTA MARGARITA *Pecten raymondi* Clark *Pecten crassicordo* Conrad *Ostrea titan* Conrad	SANTA MARGARITA	MONTESAN 5400′ congl, ss, s
		Maricopa shale 4800′			MINT CANYON Land-laid and equivalent to "Barstow" *Merychippus* 3000′		
TEMBLOR "Salinas Shale" *andersoni* Arnold *peckhami* Gabb *discus* Conrad *ella ocoyana* Conrad 5000–7000′ rganic shales	TEMBLOR "Big Blue" 300′ Merychippus coalingensis fauna "Vaqueros" *Pecten andersoni* Arnold *Chione temblorensis* Anderson *Trophon kernensis* Anderson *Agasoma barkerianum* Cooper *Turritella ocoyana* Conrad *Scutella merriami* Pack 900′ ss	TEMBLOR (Sandstones and Shales) *Pecten andersoni* Arnold *Pecten peckhami* Gabb *Chione temblorensis* Anderson *Conus oweni* Anderson *Trophon kernensis* Anderson *Turritella ocoyana* Conrad	TEMBLOR *Turritella ocoyana* Conrad "SALINAS SHALE" 6000′	?MODELO? 4500′ Organic shale	TEMBLOR (Sandstone and Shale)	TEMBLOR (Sandstones and Shales) *Pecten peckhami* Gabb *Chione temblorensis* Anderson *Turritella ocoyana* Conrad "PUENTE SANDSTONE" 4000′ (Including Vaqueros)	TEMBLO "Wahkiaku "Blakeley" *Arca devincta* C *Turritella orego* Conrad *Miopleiona indi* Conrad *Eudolium petros* Conrad 2600′ ss and s
VAQUEROS *ella inezana* Conrad *magnolia* Conrad *perrini* Arnold 500′ ss		VAQUEROS *Pecten perrini* Arnold *Turritella inezana* Conrad (Including Oligocene) 3000′ ss	? ? VAQUEROS *Pecten sespeensis* Arnold *Pecten sespeensis* Arnold, var. *hydeii* *Pecten magnolia* Conrad *Turritella inezana* Conrad *Scutella fairbanksi* Arnold 3400′ ss	? ? VAQUEROS *Pecten sespeensis* Arnold *Pecten sespeensis* Arnold, var. *hydeii* *Pecten magnolia* Conrad *Turritella inezana* Conrad *Scutella fairbanksi* Arnold 3000′		VAQUEROS *Turritella inezana* Conrad	
SAN LORENZO			SESPE* 1700′	SESPE*		SESPE*	

		CONTINENTAL DEPOSITS Vertebrate Horizons of J. C. Merriam		OTHER SECTIONS According to T. W. Vaughan[1]	
ANGELES TO SANTA NA MOUNTAINS neralized Section	GENERALIZED SECTION OF OREGON, WASHINGTON, AND NORTH CALIFORNIA COAST RANGES	GREAT BASIN PROVINCE	CALIFORNIA PROVINCE	SOUTHEASTERN UNITED STATES	EUROPEAN SECTION
SAUGUS pper Fernando" *healyi* Arnold *caurinus* Gould *opuntia* Dall *dula princeps* Conrad	UPPER PLIOCENE		UPPER ETCHEGOIN Pliohippus proversus zone	WACCAMAW SHALE Nearly Contemporaneous	SICILIAN
PICO *oweni* Arnold *wattsi* Arnold *hastatus* Sowerby *auburyi* Arnold *veatchii* Gabb *rilineata* Conrad 2000′ ss and sh	EMPIRE (of Oregon) 1000′ ss WILDCAT (of Humboldt Co., Cal.) 4600′ ss *Pecten coosensis* Shumard *Pecten caurinus* Gould *Chione securis* Shumard *Argobuccinum cammani* Dall *Dendraster oregonensis* (Clark)	THOUSAND CREEK RATTLESNAKE RICARDO *Hipparion mohavense* *Pliohippus fairbanksi*	MIDDLE ETCHEGOIN *P. coalingensis* PINOLE TUFF—ORINDAN JACALITOS CHANAC Neohipparion zone	NASHUA MARL CALOOSAHATCHEE MARL	ASTIAN PLAISANCIAN
NTA MARGARITA	MONTESANO 5400′ congl, ss, sh	BARSTOW CEDAR MOUNTAIN (Esmeralda) (Stewart V.) *Hypohippus* (*Drymohippus*) *nevadensus* Merriam	CACHE PEAK *Merychippus*	YORKTOWN DUPLIN MARL CHOCTAWHATCHEE MARL Nearly Contemporaneous	PONTIAN SARMATIAN
				ST. MARY'S CHOPTANK CALVERT	TORTONIAN
TEMBLOR dstones and Shales) *peckhami* Gabb *e temblorensis* derson *tella ocoyana* Conrad ENTE SANDSTONE" 4000′ cluding Vaqueros)	TEMBLOR "Wahkiakum" "Blakeley" (in part) *Arca devincta* Conrad *Turritella oregonensis* Conrad *Miopleiona indurata* Conrad *Eudolium petrosum* Conrad 2600′ ss and sh	VIRGIN VALLEY MASCALL *Merychippus isonesus* Cope	MERYCHIPPUS ZONE PHILLIP'S RANCH *Primitive Merychippus*		HELVETIAN
VAQUEROS *tella inezana* Conrad		(COLUMBIA LAVA)		ALUM BLUFF	BURDIGALIAN
SESPE*		JOHN DAY	TECUJA	CHATTAHOOCHEE	AQUITANIAN

Lower Miocene	Monterey Series Undifferentiated "Monterey Shale"		"Oursan Sandstone" "Claremont Shale" "Sobrante Sandstone" *Pecten andersoni* Arnold *Ostrea titan* n. var.? *Agasoma barkerianum* Cooper *Turritella ocoyana* Conrad *Pecten peckhami* Gabb 3000′ ss and sh	Arnold *Turritella ocoyana* Conrad *Pecten peckhami* Gabb 5000′ organic shale	*Pecten discus* Conra *Turritella ocoyana* 5000–7000′ organic shales
	VAQUEROS			VAQUEROS *Turritella inezana* Conrad 2700′ ss, sh, and congl	VAQUEROS *Turritella inezana* C *Pecten magnolia* Co *Pecten perrini* Arno 500′ ss
Oligocene	San Lorenzo Series	KIRKER *Cardium lorenzanum* Arnold *Acila gettysburgensis* Reagan 450′ ss and tuff	CONCORD 250′ fine ss KIRKER 100′ fine tuffs SAN RAMON *Antigona mathewsonii* Gabb *Molopophorus biplicata* Gabb *Ancilla fishii* Gabb *Agasoma gravidum* Gabb *Fusinus hecoxi* Arnold 520′ ss	SAN LORENZO *Acila dalli* Arnold *Cardium lorenzanum* Arnold *Tellina lorenzanum* Arnold *Fusinus hecoxi* Arnold *Solarium lorenzana* Arnold 2500′ ss and sh	SAN LORENZO
		Acila muta Clark *Yoldia packardi* Clark		BUTANO (Oligocene?)	
		MARKLEY 3200′ ss and sh		2100 ss	
Eocene	TEJON	TEJON *Turritella uvasana* Conrad *Turritella uvasana* Conrad, var. *Rimella canalifera* Gabb *Balanophyllia variabalis* 1100′ ss and sh	TEJON *Turritella uvasana* Conrad *Turritella uvasana* Conrad, var. *Rimella canalifera* Gabb *Balanophyllia variabalis* 1500′ ss and sh		
	MEGANOS	MEGANOS *Turritella merriami* Dickerson *Turritella andersoni* Dickerson *Turritella reversa* Waring *Siphonalia sutterensis* Dickerson *Galeodea sutterensis* Dickerson *Ancilla* (*Oliverato*), *californica* Cooper *Turbinolia pussilanima* Nomland *Schizaster diabloensis* Kew 3100′ ss	MEGANOS *Turritella merriami* Dickerson *Turritella andersoni* Dickerson *Turritella reversa* Waring *Siphonalia sutterensis* Dickerson *Galeodea sutterensis* Dickerson *Ancilla* (*Oliverato*), *californica* Cooper *Turbinolia pussilanima* Nomland *Schizaster diabloensis* Kew 2000′ ss		
	MARTINEZ	MARTINEZ *Turritella pachecoensis* Stanton *Turritella infragranulata* Gabb *Pholadomya nasuta* Gabb *Cucullea mathewsonii* Gabb *Urosyca robusta* Gabb *Urosyca caudata* Gabb *Schizaster lecontei* Merriam *Trochocyathus zitteli* Merriam 700′ congl and shale	MARTINEZ *Turritella pachecoensis* Stanton *Turritella infragranulata* Gabb *Pholadomya nasuta* Gabb *Cucullea mathewsonii* Gabb *Urosyca robusta* Gabb *Urosyca caudata* Gabb *Schizaster lecontei* Merriam *Trochocyathus zitteli* Merriam 1700′	? MARTINEZ ? 200′	

ss = sandstone
sh = shale
congl = conglomerate
* = continental deposits

[1]T. W. Vaughan "G

...discus Conrad *...ella ocoyana* Conrad 5000–7000′ ...rganic shales	*Merychippus coalingensis* fauna "Vaqueros" *Pecten andersoni* Arnold *Chione temblorensis* Anderson *Trophon kernensis* Anderson *Agasoma barkerianum* Cooper *Turritella ocoyana* Conrad *Scutella merriami* Pack 900′ ss	Arnold *Pecten peckhami* Gabb *Chione temblorensis* Anderson *Conus oweni* Anderson *Trophon kernensis* Anderson *Turritella ocoyana* Conrad	"SALINAS SHALE" 6000′	4500′ Organic shale	Anderson *Turritella ocoyana* Conrad "PUENTE SANDSTONE" 4000′ (Including Vaqueros)	*Turritella oregon...* Conrad *Miopleiona indu...* Conrad *Eudolium petros...* Conrad 2600′ ss and s...
VAQUEROS *...ella inezana* Conrad *...magnolia* Conrad *...perrini* Arnold 500′ ss		VAQUEROS *Pecten perrini* Arnold *Turritella inezana* Conrad (Including Oligocene) 3000′ ss	? VAQUEROS ? *Pecten sespeensis* Arnold *Pecten sespeensis* Arnold, var. *hydeii* *Pecten magnolia* Conrad *Turritella inezana* Conrad *Scutella fairbanksi* Arnold 3400′ ss	? VAQUEROS ? *Pecten sespeensis* Arnold *Pecten sespeensis* Arnold, var. *hydeii* *Pecten magnolia* Conrad *Turritella inezana* Conrad *Scutella fairbanksi* Arnold 3000′	VAQUEROS *Turritella inezana* Conrad	
...SAN LORENZO			SESPE* 1700′ fanglomerate, ss, sh	SESPE* 3500′	SESPE*	SAN LORE... "Astoria" of A... Hannibal, Pa... Smith "Acila gettysbu... zone" *Acila gettysburg...* Reagan *Turcicula washi...* Dall *Turritella divers...* Merriam 9000′ ss and s...
	KREYENHAGEN SHALE *Leda lincolnensis* Weaver *Macrocallista pittsburgensis* Dall *Fusinus* (*Exilia*) *lincolnensis* Weaver	KREYENHAGEN (Shales and Sandstones) Organic shales in San Emigdio Mountains 3000′				"Molopophorus lincolnensis z..." *Acila shumardi* *Macrocallista pi...* Dall *Turritella porter...* Weaver *Fusinus* (*Exili...*) *...ensis* Weaver *Molopophorus l...* Weaver 6000′ ss and s...
	TEJON *Meretrix horni* Gabb *Venericardia planicosta* Gabb, var. *hornii* *Turritella uvasana* Conrad Eocene 2300′	TEJON *Galeodea tuberculata* Gabb *Rimella canalifera* Gabb *Whitneya ficus* Gabb *Surculites sinuata* Gabb *Nyctilochus californicus* Gabb Eocene 4300′	TEJON *Pecten yneziana* Arnold *Turritella uvasana* Conrad *Turritella lompocensis* Arnold	TEJON *Venericardia planicosta* Gabb, var. *hornii* *Whitneya ficus* Gabb *Turritella uvasana* Conrad *Turris io* Gabb	TEJON *Cardium brewerii* Gabb *Venericardia planicosta* Gabb, var. *hornii* *Turritella uvasana* Conrad 1300′ ss	TEJON *Turritella uvasa...* *Ficopsis cowlitze...* Weaver *Exilia dickerson...* *Conus cowlitzens...* *Nyctilochus cowl...* Weaver 14,000... Eocene
	MEGANOS *Turritella andersoni* Dickerson *Turbinolia pussilanima* Nomland *Natica hannibali* Dickerson	MEGANOS	MEGANOS *Turritella merriami* Dickerson *Turritella reversa* Waring Topatopa	MEGANOS *Turritella andersoni* Dickerson *Turritella reversa* Waring *Turris* (*Surculites*) *crenatospira* Cooper *Clavilithes tabulata* Dickerson TOPATOPA 5000′ Exposed		MEGANO... *Venericardia pl...* var. *merriami* *Turritella and...* Dickerson *Siphonalia su...* Dickerson *Natica hannibal...* Dickerson *Ancilla* (*Olivera...*) *...fornica* Coope...
			TOPATOPA 10,000′ Shales and thin-bedded sandstones	? MARTINEZ ? *Venericardia venturensis* Waring *Turritella pachecoensis* Stanton *Turritella macreadyi* Waring *Cucullea mathewsonii* Gabb	MARTINEZ *Crassatellites unioides* Stanton *Turritella pachecoensis* Stanton *Turritella infragranulata* Gabb 1500′ ss	

Vaughan "Geologic History of Central America and the West Indies during Cenozoic Time," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), tables.

TENTATIVE

...derson ...*tella ocoyana* Conrad ...ENTE SANDSTONE" 4000′ (...cluding Vaqueros)	*Turritella oregonensis* Conrad *Miopleiona indurata* Conrad *Eudolium petrosum* Conrad 2600′ ss and sh	MASCALL *Merychippus isonesus* Cope	PHILLIP'S RANCH *Primitive Merychippus*		
VAQUEROS ...*tella inezana* Conrad		(COLUMBIA LAVA)		ALUM BLUFF	BURDIGALIAN
SESPE*	SAN LORENZO "Astoria" of Arnold, Hannibal, Packard, and Smith "Acila gettysburgensis zone" *Acila gettysburgensis* Reagan *Turcicula washingtoniana* Dall *Turritella diversilineata* Merriam 9000′ ss and sh	JOHN DAY	TECUJA	CHATTAHOOCHEE	AQUITANIAN CHATTIAN RUPELIAN
	"Molopophorus lincolnensis zone" *Acila shumardi* Dall *Macrocallista pittsburgensis* Dall *Turritella porterensis* Weaver *Fusinus* (*Exilia*) *lincolnensis* Weaver *Molopophorus lincolnensis* Weaver 6000′ ss and sh			VICKSBURG GROUP	LATTORFIAN (Sannoisian)
				JACKSON | OCALA	LUDIAN (Priabonian) BARTONIAN
TEJON ...*um brewerii* Gabb ...*icardia planicosta* ...bb, var. *hornii* ...*tella uvasana* Conrad 1300′ ss	TEJON *Turritella uvasana* Conrad *Ficopsis cowlitzensis* Weaver *Exilia dickersoni* Weaver *Conus cowlitzensis* Weaver *Nyctilochus cowlitzensis* Weaver 14,000′ Eocene			CLAIBORNE GROUP	LUTETIAN
	MEGANOS *Venericardia planicosta*, var. *merriami* Dickerson *Turritella andersoni* Dickerson *Siphonalia sutterensis* Dickerson *Natica hannibali* Dickerson *Ancilla* (*Oliverato*) *californica* Cooper			WILCOX GROUP	YPRESIAN SPARNACIAN
MARTINEZ ...*satellites unioides* ...nton ...*tella pachecoensis* ...nton ...*tella infragranulata* ...bb 1500′ ss				MIDWAY GROUP	THANETIAN ? MONTIAN ?

...bles.

TENTATIVE CORRELATION DRAWN UP UNDER THE DIRECTION OF B. L. CLARK, BY T. H. CROOK, MAY, 1920